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# Cooperative Network Analysis of Patent Holders in the Field of OLED Technology

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## Abstract

With the continuous development of science and technology, the number of patents continues to increase. At the same time, patent cooperation is more normal. It is particularly important to analyze the cooperation relationship among patent holders. The application of social network analysis methods solves this problem. OLED tends to gradually replace LCD. South Korea's Samsung and LG hold the majority of patents in the OLED field. How to break through has become a problem faced by Chinese companies. This paper uses the degree centrality, betweenness centrality and closeness centrality in the social network analysis method, and uses the data visualization tool Ucinet to systematically analyze the OLED technology patents from the Derwent Innovation Index. The results show that there is a clear trend of cooperation among patent holders in the OLED technology field. China's OLED enterprises should speed up the industrial chain layout, increase relevant R&D investment, and improve the R&D intensity of core technologies.

## Introduction

The rapid development of the information technology industry has brought great convenience to people's lives, among which the display industry is an important pillar of the information technology industry, showing that the industry has the advantages of high added value and wide application, but also has a strong pulling effect on other industries（Wang et al. 2018）. Display technology involves all aspects of production and life, including business, communication, computer, industry and military fields, etc. Therefore, the development of display technology is of great significance to economic development. In the short 30 years of the development of display technology, it has experienced the technological change of CRT - LCD - OLED. In recent years, organic light emitting diodes (OLED) have replaced LCD gradually.

Compared with LED, OLED has many advantages: self - emission, wide viewing angle, low energy consumption, flexibility, etc. Based on the superior performance of these OLED's, the world's major display manufacturers are stepping up their industrial layout. At present, OLED technology in the world is almost monopolized by South Korea's Samsung and LG. Samsung mainly develops small screens for mobile phones, while LG mainly focuses on large screen displays. In addition, Sony in Japan and Innolux Display and AU Optronics in Taiwan are also speeding up the research and development of OLED. The mainland of China started late in this field and is still in the period of industry introduction and technology growth. The

industrial chain is mainly focused on panel manufacturing, and the upstream equipment and raw materials are mostly imported from Japan and South Korea. This link is relatively weak. However, there are also many relatively strong enterprises in the mainland OLED field, such as BOE, CSOT, Visionox and so on.

Patent as a technology carrier is an important part of scientific discovery. According to statistics, the patent literature contains more than 90 % of the world's scientific and technological information (Wen et al. 2012). With the patentee, IPC, inventor, etc. in patent information as nodes, and the relationship of reference and cooperation as links, knowledge flow network can be constructed, and knowledge diffusion, knowledge transfer, and knowledge overflow can be measured more accurately. Companies often use patent cooperation to promote the improvement of their own technology level, such as LG Philips LCD Co., Ltd., which established in cooperation with Philips and LG. Visionox 's long-term OLED technology cooperation agreement with General Display, etc. These examples show that cooperation in this field is becoming more and more universal.

**Literature Review**

Organic Lighting Emitting Display (OLED) refers to the technology that organic semiconductor materials emit light under the action of electric field. OLED is an all-solid-state structure that actively emits light without backlight, and is called " dreamlike display technology" by the industry. OLED is one of the most promising new display technologies and also a competitive hot spot in the international high-tech field (Zhang 2011). The phenomenon of organic electroluminescence was first discovered in the 1960s, but it could not be truly industrialized due to a series of technical bottlenecks. Ching W. Tang and Van S Lyke provided breakthrough progress for OLED development in 1987 (Bernard et al. 2006). In 1990, Cambridge University discovered organic electroluminescent display technology from polymers, which greatly promoted the rapid development of OLED technology. After more than 30 years of technological evolution, OLED technology has achieved many technological breakthroughs and gradually matured. This technology has been industrialized in the field of display and lighting, and has become the most potential and promising new display technology in the future instead of CRTS and LCDS (Burroughes et al.1990).

Scholars have made a detailed analysis of OLED technology patents, including the number of patents, patentees, IPC and the distribution of patents in the country. In terms of quantity, the total number of OLED patent applications has been slightly tightened from 2005 to 2010, but the overall trend is increasing. Research shows that the number of patents varies significantly from country to country. Duan Keyu (2013) discovered through searching the VEN patent database that American scholars studied OLED at the earliest time and the research level was at the world's leading level, but the patent number advantage was surpassed by South Korea, mainly focusing on the fields of electroluminescent materials, electroluminescent power sources, electroluminescent panels and so on. As for the patentee, the patentee of OLED mainly concentrated in East Asia, Europe and America, the early research of OLED technology mainly concentrated in Europe, and the industrialization of OLED technology mainly concentrated in East Asia. Zhao Xuewu et al. (2010) analyzed OLED patent data from three patent databases of SIPO, USPTO and EPO, and found that the main OLED patent applicants are flat panel display manufacturers or flat panel technology licensing companies,

and there are more companies with high patent holdings in China, Japan and South Korea. As for IPC, OLED patents mainly involve fields such as H01L (semiconductor device), H05B (electric heating), G09G (static indicating device composed of a combination of several light sources), G02F (device or device for controlling the intensity, color, phase, polarization or direction of light), etc. The main technical fields involved by different patentees are different. Luo Jiaxiu et al. (2011) compared with the patent layout of four companies (Sony, Samsung, RiTdisplay and Visionox) in the United States, found that Sony mainly concentrated on control devices and circuits, Samsung and Visionox mainly concentrated on components such as electrodes, and RiTdisplay mainly concentrated on solid-state devices.

The basic patents of OLED are mainly owned by Kodak, Cambridge Display Technology (CDT) in Britain and Universal Display Company (UDC) in the United States. Among them, the basic patents of small molecule OLED are mainly owned by Kodak, and the basic patents of polymer OLED are mainly owned by CDT and Uniax in the United States (Luo et al. 2011). These companies naturally become the main members of OLED cooperation. Kodak is an OLED research company with the largest number of core patents. In 2009, Kodak adjusted its development direction and sold OLED technology to LG, but reserved the right to use the patent. At the same time, LG set up the company Global OLED Technology in the United States to expand its influence in the Americas. In order to realize the industrialization of polymer OLED technology, Britain's Cambridge Display Technology Company (CDT) actively participates in technology diffusion. In 2007, CDT was acquired by Sumitomo Chemical and its research strength was further integrated. This kind of cooperative relationship exists widely in OLED technology field, and the social network analysis method can show the complete cooperative network relationship.

At present, scholars mainly study OLED patents from the perspective of quantitative analysis, while few scholars use social network analysis to study OLED patents. With the help of this method, the cooperative relationship between patentees can be visually analyzed, and a leading enterprise of technology can be found. In addition to regular quantitative analysis, scholars also use data visualization software to make a network so as to observe the network structure more intuitively. Common social network data visualization software includes Netdraw, Pajek, Gephi, Citespace and so on. Wang Lijie (2016) takes the Institute of Polymer Optoelectronic Materials and Devices of South China University of Technology as the research object, selects inventor information in patent information as the index to construct inventor co-occurrence matrix and Jacard co-occurrence matrix, and constructs the network diagram through Ucinet, and systematically analyzes the network structure with three indexes of degree centrality, betweenness centrality and closeness centrality.

With the support of various indicators of social network analysis and various data visualization tools, this method has been applied to patent analysis in various fields. Wang Hailong et al. (2017) searched patents in the semiconductor field through USPTO, and constructed a network based on the citation relationship between patents. An evaluation system was set up through six indicators, namely, the degree of output, the degree of input, the degree of betweenness, the degree of closeness, the effective scale and the limitation. An empirical study was conducted on the identification of patent-based technologies in the semiconductor field. Gong Jintao et al. (2013) have conducted empirical research in this field through the patents of wind power generation technology in China's patent database. They

have conducted network cohesion analysis, network connectivity analysis and network centrality analysis through different theories in social network analysis. They believe that the technical research and development directors and core researchers in this field can be identified through this complex network analysis. Breschi Stefano et al. (2009) systematically analyzed the contribution of the transfer of inventors' and inventors' networks to knowledge dissemination within enterprises and within cities or states using social network analysis methods based on the original data set of patent applications filed by U.S. inventors in the European patent office.

**Data**

The patent data in this paper comes from Derwent Innovations Index. The formulation of keywords and the retrieval strategy adopted the scheme reported by Alan L Porter in 2008, that is, the keywords are first extracted from the literature, then the keywords are revised and the retrieval formula is determined by consulting experts in the field, and the retrieval formula is continuously optimized and adjusted through the retrieval results (Carley et al. 2013). The retrieval period is from 1967 to 2018. As of the final retrieval date of this article, 23235 patent data have been retrieved, and 23197 patent data have been obtained after cleaning. Then, we use the patentee index in the database to analyze the social network.

**Results and Analysis**

*Overall Network of Patentees*

According to the statistics on the number of patents held by the patentee, the top 10 patent holders are intercepted as shown in Table 1. OLED technology patents are mainly concentrated in South Korea, Japan, mainland of China and Taiwan of China. Four of the top 10 patent holders are from Samsung Group, which shows Samsung's strong dominance in this field, and South Korea's LG Company also has a large number of patents in OLED field. Kodak owns 435 OLED patents in the United States. Kodak is an early developer of OLED display technology and holds most of the basic technology patents. China's BOE is active in OLED technology research and development, with the third largest number of patents, after Samsung Display Co., Ltd. and LG Display Co., Ltd. But at the same time, nearly half of the technology patents in the OLED field in mainland China are utility models. Because OLED is a new industry. Chinese enterprises can increase R & D investment and strengthen international cooperation to achieve overtaking in corners.

**Table 1. Patentee and its possession patent statistics**

| *Ranking* | *Patentee* | *Quantity* |
|---|---|---|
| 1 | Samsung Display Co Ltd | 3267 |
| 2 | LG Display Co Ltd | 2669 |
| 3 | BOE Technology Group Co Ltd | 1311 |
| 4 | Samsung Electronics Co Ltd | 1244 |
| 5 | Samsung Mobile Display Co Ltd | 1052 |
| 6 | Samsung SDI Co Ltd | 716 |
| 7 | LG Philips LCD Co Ltd | 589 |
| 8 | Eastman Kodak Co | 435 |
| 9 | Au Optronics Corp | 362 |
| 10 | Shenzhen China Star Optoelectronics Tech | 329 |

A single quantity ranking cannot show the relationship between patent holders. To this end, the patentee data is organized into a co-occurrence matrix through the Bibexcel, and then the

co-occurrence matrix is imported into Ucinet for mapping. The result is shown in Figure 1.
In the network of OLED technology patentees, large networks coexist with small groups, which have a network structure of less than ten people. Large networks have a high density, and different nodes are closely connected. There are many important nodes that play a bridging role. These nodes represent enterprises or individuals holding important OLED patents. This reveals the current research and development status of OLED technology. Samsung, LG, Philips and other companies in Europe have mastered many basic patents and become major networks centering on them. At the same time, there are many small research and development teams in colleges and universities, which do not cooperate with large enterprises, but also have strong research and development capabilities.

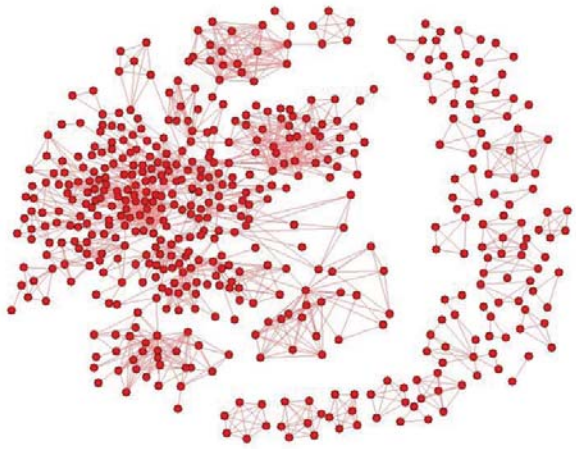

**Figure 1. Co-occurrence network of Patentee**

*Right holder's communication ability*

Centrality is an important index in the analysis of social networks. Through the evaluation of the position of the central performance node in the network, which patentees play a key role in the patent cooperation network can be evaluated. Centrality analysis includes main three parts: degree centrality, betweenness centrality and closeness centrality. Through the comparison of three types of centrality, the communication ability, control ability and independent ability of enterprises in OLED technology field can be clearly compared.
Degree centrality is the most direct measure to describe the node center in network analysis. The greater the degree centrality of a node, the higher the degree centrality of the node, and the more important the node is in the network. The greater the degree centrality of a patentee, the more central it is in the network. The degree centrality of patentees is calculated by using Ucinet and the list of the top 5 patentees is shown in Table 2. The top six patentees are subsidiaries of Samsung Group: Samsung Mobile Display Co., Ltd., Samsung Display Co., Ltd., Samsung SDI Co., Ltd., Samsung DenKan Co., Ltd., Samsung Electronics Co., Ltd. and Samsung Mobile Display Co., Ltd. Secondly, Lee's independent patentee is also from Samsung Group, which shows Samsung Group's strong monopoly power in OLED technology field, and at the same time, the group's internal ties are very close, the subsidiaries cooperate with each other, and the research and development intensity is greatly enhanced.

**Table 1. Degree of patentee ranking**

| *Ranking* | *Patentee* | *Degree* |
|---|---|---|
| 1 | Samsung Mobile Display Co Ltd | 1557.000 |
| 2 | Samsung Display Co Ltd | 1520.000 |
| 3 | Samsung SDI Co Ltd | 832.000 |
| 4 | Samsung DenKan Kk | 620.000 |
| 5 | Samsung Electronics Co Ltd | 406.000 |

Use the Netdraw to draw out the nodes with greater centrality, as shown in fig. 2. It can be seen that they are all teams with very strong scientific research strength. Apart from South Korea's Samsung scientific research team, the patentees such as Princeton University and the University of Southern California in the United States also have very close ties. There are also teams from Siemens, Osram, Merck and Philips of the Netherlands, which also play an important role in OLED patentee networks. These enterprises gradually formed patent alliances through patent cooperation, which promoted the development of their own technical level.

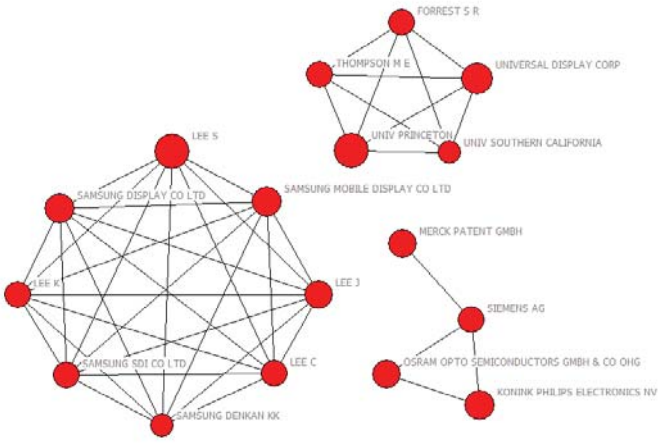


**Figure 2. Network of patentee's degree**

*Rights holder's control ability*

If a node is between other node pairs in the network and is on the only way to communicate with each other between node pairs, the node must have a very important position in the network. Therefore, mediation centrality is interpreted based on the node's control over communication. Through mediation centrality analysis, we can find the network's community bridge or communication bottleneck or cross - border. Sorting out the information about the patentee's betweenness centrality is shown in Table 3. The higher the centrality of intermediaries, the greater the patentee's control over the network. The most central intermediary is Konink Philips, which mainly produces large-sized OLED screens, while Samsung Electronics, which is in second place, mainly sells small-sized OLED screens. The two companies hold important technologies in OLED technology. In recent years, Philips of the Netherlands, in order to consolidate its position in OLED large screen displays, has entered into various cooperation with LG of South Korea, which is also in the leading position in technology, and has jointly established LG Philips Display Co., Ltd., which will cause more restrictions on the development of OLED large screen displays in China.

**Table4. Betweenness of patentee ranking**

| *Ranking* | *Patentee* | *Betweenness* |
|---|---|---|
| 1 | Konink Philips Electronics Nv | 23301.998 |
| 2 | Samsung Electronics Co Ltd | 19525.879 |
| 3 | Eastman Kodak Co | 14888.331 |
| 4 | NXP Bv | 10590.000 |
| 5 | Semiconductor Energy Lab | 9631.417 |

As shown in Figure 3, the patentee's network is drawn with the betweenness as an index. The node size represents the patentee's betweenness centrality. Samsung Electronics, Kodak and Philips play a very important control role in the network. Merck, Siemens, and other 12 companies have formed a cooperation circle structure, effectively promoting OLED technology research and development, but this has also formed a barrier to other enterprises. Within the circle structure, there are many patent holders in Samsung, including various subsidiaries and related independent patent holders. Samsung Group controls many related technical resources. Chinese OLED enterprises should deepen their cooperation with related companies in the network, strengthen the distribution of foreign patents, strive to obtain authorization for core patents or sign licensing agreements, and break through the intellectual property barriers and restrictions in international trade.

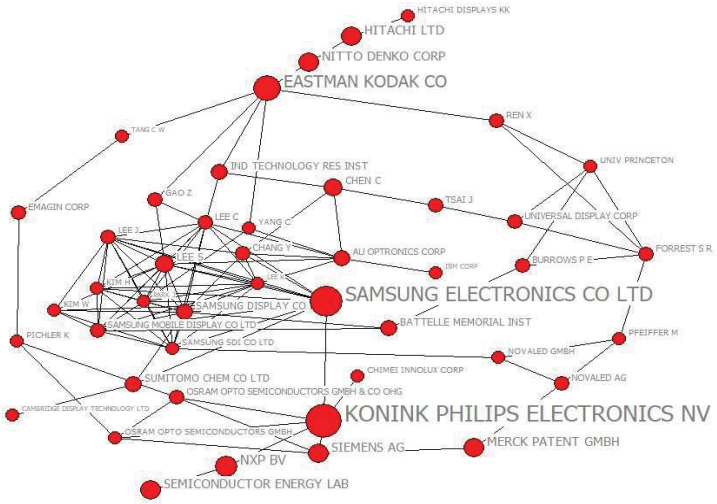


**Figure 4. The network of patentee's betweenness**

*Independent Capacity*

Closeness centrality: Closeness centrality describes the ability of actors in a network not to be " controlled" by others. It refers to the extent to which most direct paths connecting one node to all other nodes in the network are short (rather than long). The closer the center is, the smaller the node is in the core position in the network. The smaller the betweenness centrality of a patentee, the more information it can obtain. Sort out information about patentee's proximity to centrality as shown in Table 4. The top five places closeness centrality in the table belong to Samsung Group, indicating the close degree of cooperation within Samsung Group. The table shows that 11 of the top 20 patents close to centrality are individuals. It can be seen that the strength of the individual team cannot be ignored in OLED research and development. Chinese enterprises can introduce these talents or cooperate with independent teams when developing OLED. Enterprises and individuals from other countries have long-term OLED patent layout in China, becoming the patentee of important technologies in

China, and some technologies are concentrated in blank areas of OLED technology in China, which severely restricts the research and development of OLED technology in China.

**Table 4. Closeness of patentee ranking**

| *Ranking* | *Patentee* | *Closeness* |
|---|---|---|
| 1 | Samsung Electronics Co Ltd | 3145.000 |
| 2 | Lee S | 3194.000 |
| 3 | Lee C | 3208.000 |
| 4 | Samsung Display Co Ltd | 3209.000 |
| 5 | Samsung Mobile Display Co Ltd | 3237.000 |

*Community Analysis*

G-N algorithm is a splitting algorithm for subgroup discovery proposed by Girvan and Newman (2002). According to the description of the community, the internal nodes of the community are densely connected and the connections between the communities are relatively sparse. A few connections between subgroups will become the only way for communication traffic between subgroups. Considering some form of communication in the network and finding the edge with the highest traffic, removing the edge will get the most natural segmentation of the network. Therefore, Girvan and Newman introduced edge betweenness centrality to measure network traffic, and proposed a subgroup discovery algorithm based on edge betweenness, called G-N algorithm for short (Deng et al. 2012).

Through this clustering analysis, the main patent holder network in OLED field is divided into four communities as shown in fig. 5, in which nodes of different colors and shapes represent different communities. The blue community is the largest community in OLED, with Samsung Group as the main group, including Samsung Electronics, Samsung Display, Samsung Mobile Display and so on, as well as LG, Sumitomo and AU Optronics. The cooperation between AU Optronics and Samsung began in 2006, when the two sides signed a patent cross license. The green community is mainly European enterprises, and the representative enterprises are Konink Philips Electronics, NXP, Siemens, Osram and so on. On January 28, 2007, OSRAM and Philips reached a cross-licensing agreement for LED and OLED, which covers patents held by Philips and its U.S. subsidiary Lumileds and OSRAM and its subsidiary OSRAM Opto Semiconductor S. (Luo et al. 2011). Red community are mainly American patent holders, involving scholars, enterprises and universities, among which Princeton University, the University of Southern California, the University of Michigan, Motorola and UDC are allies. UDC cooperated with Princeton University, the University of Southern California and the University of Michigan in research and obtained Motorola's sole license to transfer. Among them, Kodak is the key node, because it holds many core patents, so it is very strict in patent licensing. At the same time, the granted enterprise must license all its own patents to Kodak free of charge. The yellow community is Chinese Taiwan enterprises and researchers. The core node is Professor Chen Chin Hsin, Deputy Secretary General of Taiwan Industrial Research Institute and China OLED Industry Alliance.

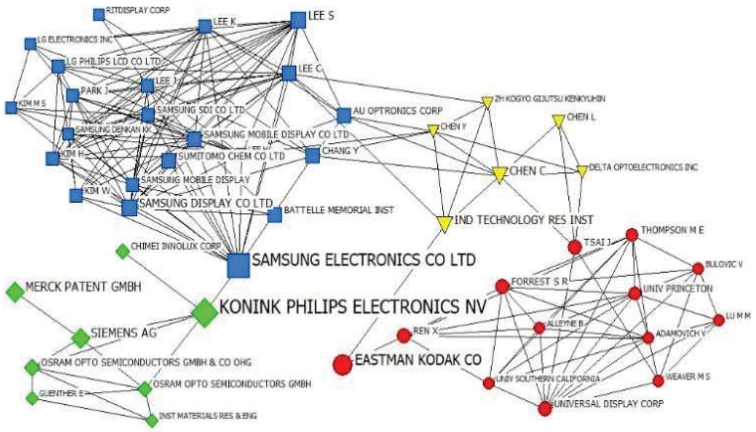


**Figure 5. Patentee clustering network**

## Conclusion and discussion

It can be seen from the above that there is extensive patent cooperation in OLED technology, including patent alliance, patent cross licensing and other forms. South Korea holds the largest number of patents in OLED field, and each subsidiary of Samsung Group and its independent patentees within the group have close cooperation. Although the amount of patent disclosure in Europe and America is not as large as that in Asian countries, through network analysis, it is found that many enterprises in Germany, the Netherlands and the United States are still in a very important position in OLED field, such as Kodak, Philips and other enterprises, which is also proving the importance of basic technology patents controlled by European and American patent holders.

Although mainland China ranks very high in OLED patents, there are no mainland Chinese enterprises in the three central rankings in network analysis. First of all, mainland OLED companies started late, starting from the end of the value chain, mostly in a generation-by-generation processing relationship with the world's major OLED companies, and have not yet integrated into the world's major patent cooperation networks. Secondly, the major OLED enterprises have formed patent alliances, which are of great help to the technological upgrading of their internal members, but at the same time, they have caused great obstacles to the development of enterprises outside the alliance.

In order to realize the substantial breakthrough of OLED technology, Chinese enterprises should increase their scientific research intensity, move upstream into the global value chain, invest in new industries, and quickly form the results of scientific and technological transformation, and form a patent layout as soon as Possible. OLED enterprises can strengthen the cooperation with domestic and foreign display terminal products enterprises, as soon as possible to build a perfect alliance to expand the upstream and downstream Layout. Speeding up the establishment of industry standard system dominated by Chinese enterprises, such as Chinese enterprises can seize this opportunity, can significantly enhance the competitiveness of Chinese enterprises, while effectively weakening the foreign companies to China's OLED industry monopoly. In the OLED patent cooperation network, the number of enterprises in mainland China is relatively low, the relevant enterprises can take appropriate cooperative authorization mode, in order to seek their own development, fill the gaps in their

technical fields, and promote industrial transformation and upgrading. The establishment of a patent cooperation network suitable for the growth of enterprises can help enterprises realize the complementarity of resources and reduce the risk challenges in the process of Innovation. At the same time, the government can provide policy concessions to promote international patent cooperation as a model of knowledge flow, in the process, enterprises should enhance the absorption of knowledge, so as to enhance their innovative ability.

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